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A Review of Costs of US Evolved Expendable Launch Vehicles (EELV)

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Summary

Much debate has centered on the real costs of the United States Evolved Expendable Launch Vehicles (EELVs) and associated infrastructure. Often the consideration of cost is phrased in terms of systems that do not carry humans "versus" the Space Shuttle Human Space Flight Operation. Naturally, as NASA moves to the new human space flight architecture, the Constellation program, there is a desire for comparisons to the most recent expendable systems developments. The most recent US launch vehicles and systems developed and now operating are the Lockheed-Martin Atlas V and the Boeing Delta IV.

Nonetheless, valid, transparent comparisons between Human Space Flight and Expendable systems have been prevented by various roadblocks. First, detailed cost data for the EELVs has been designated "sensitive", "classified", or worse, "proprietary" under assorted National Security justifications or as simply standard operating procedure. This makes any comparison to the Space Shuttle, a highly studied program with a relatively well documented cost picture, impossible simply for lack of EELV cost data of any quality. Second, even when some data has been accessible to a select few, a good picture of EELV costs can never evolve within the process of critique and broad peer review by the interested community to a degree that creates broad consensus as to the meaning or validity of the data or comparison. Numbers never pass the level of the anecdotal. Third, the comparison of Human Space Flight vs. Expendable Launch Vehicles is beset by the syndrome of comparing un-equal requirements. What would a Shuttle cost, minus a crew, with an expendable cargo carrier, but with a commercial payload, as a service contract? What would an EELV cost equivalent be to meet the Shuttle fleets combined human, cargo and scientific experiment / on-orbit time requirements in any given year? This may be as easily resolved as asking weather apples or oranges taste better.

The un-ambitious purpose of this paper, therefore, is to review and compare what has been said in the interest that continued discussion keeps the topic relevant. By being relevant it is possible that one day more openness will surface as to EELV production and operations so as to improve our journey to space. Hence the resulting heavy use of footnotes. By comparing public sources the later issue of fair "apples to oranges" comparisons will be enhanced, if not resolved, for future consideration.

> *"Give me a recent business graduate and access to the internet, and we can deconstruct any companies costs within plus or minus 10% in 24 hours"* - Opening Presentation [remarks/speech] Supply Chain World North America 2006, "Integrating for Efficiency, Productivity and Growth", Robert W. Moffat, Jr. - Senior Vice President Integrated Operations- IBM

An Atlas common core booster in the Atlas Spaceflight Operations Center (ASOC)

A Delta common core booster in the Delta Horizontal Integration Facility (HIF)

1. Background

The EELV program set off as an in-direct result of numerous events, such as Challenger in 1986, and more directly from momentum and numerous studies that justified updating aging, costly, expendable flight and ground launch systems. One Cold-war remnant, the Titan 4, ran a steady bill of about [1]$1B per year even when launches steadied at only 2 per year for many years. The original EELV plan in 1995 was to have various contractors compete in developing new systems to win what would eventually be awarded as a [2]single contract for Department of Defense (DoD) launches. The winner would be expected to supplement the yearly manifest with commercial launch contracts. Any large military-industrial / aerospace contractors that were on the losing side of the bids would still have growing commercial launch prospects as well with which to persist as a national asset in the business of launch. When the global commercial launch market [3]tanked, instead, the DoD awarded two contracts to proceed toward establishing new launch capabilities in [4]October of 1998, thus maintaining strategic national capabilities. Tactical [5]redundancy was argued as an added benefit of this acquisition approach. Should one system fail and be grounded for the duration of an investigation or test-fail-fix cycle, another would still be readily available. [6]Abandoning any semblance of competition was further solidified by 2005 as re-negotiations ensued to establish new contractual agreements between DoD and the EELV providers.

The first Atlas V lifted off from Cape Canaveral in August 2002 and the first Delta IV launched in November 2002. Both were successful.

A Delta IV
Heavy Launch

[1] http://www.fas.org/spp/military/program/launch/titan_c.htm and
http://www.globalsecurity.org/space/systems/titan_c.htm

[2] "The U.S. Evolved Expendable Launch Vehicle (EELV) Programs", Federal Aviation Administration, Commercial Space Transportation Quarterly Launch report, 1997 at
http://www.faa.gov/about/office_org/headquarters_offices/ast/media/sr_97_1q.pdf

[3] The launch industry depression: when will it end? by Jeff Foust *Monday, March 17, 2003* at
http://www.thespacereview.com/article/10/1

[4] http://www.fas.org/spp/military/program/launch/eelv.htm "The program office completed its Source Selection in October 1998 and awarded Development and Initial Launch Services contracts to Boeing and Lockheed Martin."

[5] Actually, satellite can not simply be moved, due to a delay in one rocket, onto another rocket. This tactical scenario may have had more to do with consideration of a catastrophic loss of a launch pad or long lead major piece of infrastructure than with the fanciful notion of actually re-booking satellites immediately from one vehicle to another after the failure of a vehicle, or a related satellite loss, during ascent or orbit insertion.

[6] "Rocket Boosters, To Prop Up Domestic Rocket Industry, Air Force Abandons Competition", Aviation Week & Space Technology, April 18, 2005.

2. EELV Costs – What are we Talking About?

Any foray into costs needs basic definitions.

- Price: That amount of funds usually defined as a procurement, acquisition, purchase, material, service or otherwise external cost to the buyer of the launch vehicle service, exclusive of payload costs which are internal facing to the customer. These are funds that transfer from the customer and are received by the provider.

- Total Costs to the Government as DoD: That cost to interface, manage or otherwise assure, communicate, convey, enable or work with the launch provider such that requirements are assured, from the perspective of the customer, as having been satisfied by the launch provider. Includes Air Force personnel, contractors supporting these and any related charges that assist in interfacing the customer to the provider but which are not part of the funds transferred nor part of the "price". Also includes any necessary support provided as a direct transfer by the government, such as for infrastructure, to assure the launch provider's costs not adequately addressed in any price associated with direct launch activity are reimbursed. Also includes the "price" and therefore reflects a total cost.

- Total Costs to the Government as NASA: Similar to the prior definition for DoD, with one exception, that NASA does not bear primary responsibility for the management of the program nor is NASA required to contribute towards infrastructure as is DoD (more on this ahead). Includes civil servants, contractors supporting the civil servants, and any related charges that assist in interfacing the customer to the provider but which are not part of the funds transferred nor part of the "price".

The later "costs", to the Government, are the focus here. These may also be thought of as "expenses" due to a necessary distinction related to *actual launches*. In such government operations, from a DoD perspective, failure to produce, in this case launches, may not result in actual savings or any cost avoidances. When technical or other launch issues arise the strategic and cultural notion that "we're in this together" over-rides any consideration that a product has not been delivered as promised and paid for. It is considered that to do otherwise would, given that problems will inevitably arise, only destroy the national capability to launch national security payloads. Volatility would reign, as players would enter and leave the market routinely, which is not tolerable to National Security. Therefore, regardless of launches, expenses are incurred generally in alignment with *plans for launches*, not actual launches, as plans affect production, on-going capability, and so forth. Therefore, expenses, or that is "real costs" will often have nothing to do with launches. Additionally, the launch industry in general, and this equally applies globally, is relatively immune at each national level from the vagaries of competition. In this industry, even after contracts are signed that state a price, or after a yearly budget cycle is over, it is possible to cover a contractors [7]losses from one year in a subsequent year, to make them whole. One could imagine the response of government procurement officials and lawyers to a small business request that more money be paid today for what was already contracted via fixed-price contracts, paid for in full, and delivered some years before.

[7] Page 8 of GAO report "Defense Space Activities: Continuation of Evolved Expendable Launch Vehicle Program's Progress to Date Subject to Some Uncertainty" July 24, 2004 at http://www.gao.gov/new.items/d04778r.pdf

3. EELV Costs - Initially

[8]In 1998 EELV initial launch services contracts were awarded that pegged the cost of each launch to the Air Force at ***$72M*** each. It was still in program documents that these launch costs be a reduction relative to past launch costs–

> "[9]*We want to develop a family of vehicles that is technically achievable and costs 25% less (threshold) than current systems with an objective of 50% reduction in the cost of spacelift."*

4. EELV Costs – Eventually

By 2001-2002 launch costs to NASA were in the range of [10]***$87M-$107M*** (**Figure 1**).

Eventually it became clear that the costs perspective provided early in the EELV program hinged on volume, whereby commercial customers would be so abundant as to cumulatively contribute, in the commercial prices charged, to defraying an assortment of costs.

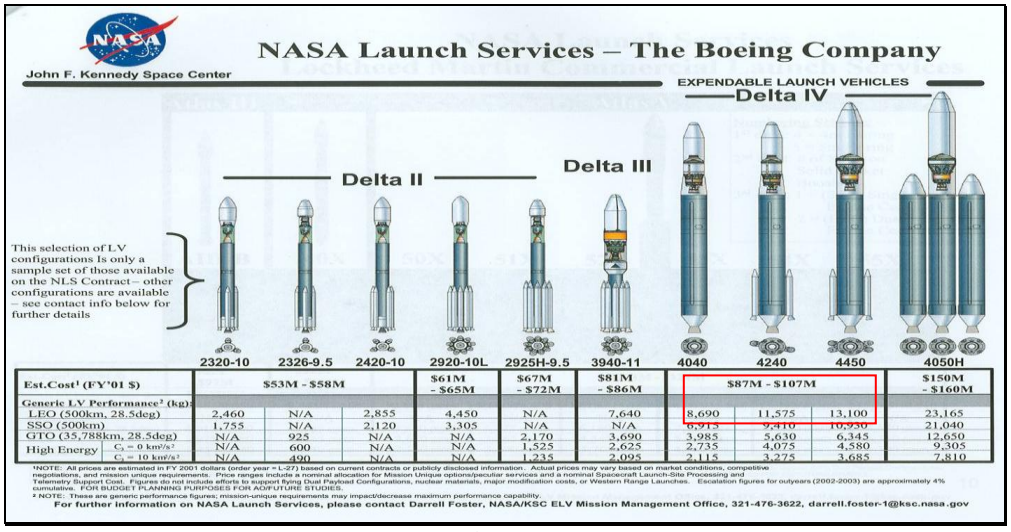

Figure 1

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[8] i.e. dividing the total over the number of launches yields the $72M/launch, at http://www.globalsecurity.org/space/library/news/1998/b10161998_bt538-98.html
"The two companies are also being awarded contracts for Initial Launch Services for the Department of Defense's Evolved Expendable Launch Vehicle Program, the next generation of space launch vehicles, that total $2.03 billion. Boeing will receive $1.38 billion, and Lockheed Martin will receive $650 million. … During the initial launch service phase, the Air Force will acquire commercial launch services for 28 government payloads scheduled to launch between fiscal years 2002 and 2006. Boeing will conduct 19 launches and Lockheed Martin nine launches."

[9] "AIR FORCE SPACE COMMAND OPERATIONAL REQUIREMENTS DOCUMENT (ORD) II AFSPC 002-93-II FOR THE EVOLVED EXPENDABLE LAUNCH VEHICLE (EELV) SYSTEM" at http://www.globalsecurity.org/space/library/report/1998/eelv-ord.htm

[10] Discovery Program Workshop, ELV Launch Services, Darrel Foster, ELV Mission Management Office, July 24, 2002.

Just one year later, in 2002 the notion that fixed costs existed was becoming accepted –

> "[11]*Sources tell this column that the package will be "in the range of $350 to $400 million initially and will compensate Boeing and Lockheed Martin for the cost of maintaining the full range of EELV configurations now in existence."*

By 2005 other [12]information was made public that the above non-recurring infrastructure charge ended at $340M in the fiscal year 2006 budget. Similarly, per launch pricing had increased from the initial 1998 value of $72M a launch to ***$170M*** a launch, but this had already been established in previous award updates –

> "*Furthermore, Arnold [Lt. Gen. Brian Arnold] says the actual pricing is not expected to change dramatically. Based on the Fiscal 2006 budget request, an average EELV launch and associated services cost about $170 million".*

Compounding the confusion amidst the escalation in price was the apparent occasional attribution of non-recurring development costs into the EELV per launch costs such as [13]quotes surfaced at **$230M** per launch in the 2004 timeframe.

Lastly, even the infrastructure payment per year had become debatable as "[14]The total EELV sustainment payments from 2004-2020 average $818 million per year on a straight-line basis."

As shown, numerous sources appear to have reverse calculated EELV "costs" or "expenses" in some very useful ways, regardless of designated claims of sensitive, classified or proprietary. Two basic categories repeat, well known from Business 101. Costs are fixed and variable, with variable assuming some level of production (otherwise it would mostly all be fixed).

5. Some Source Data

It is of value to seek source data for EELV, on a par with high-level Shuttle budget documents and costs analysis which abound. While some [15]excellent distillations exist on the subject of EELV costs, a reference to the source of data and a walk-through of logic can serve to further the development of standard definitions and thus understanding.

A year of interest is 2006, when a budget plan would show the actual budget increase resulting from the new "infrastructure" hit. A particularly useful site is the [16]Defense Technical Information Center (DTIC) (**Figure 2**).

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[11] "Spacelift Washington: USAF planning additional EELV funding" at http://www.spaceref.com/news/viewnews.html?id=426

[12] Aviation Week & Space Technology, April 18, 2005, "Rocket Boosters, To prop up domestic rocket industry Air Force abandons competition".

[13] Business Week, "The Air Force Fails Rocket Science", December 7, 2005, Commentary by Stan Crock at http://www.businessweek.com/bwdaily/dnflash/dec2005/nf2005127_4095_db046.htm

[14] U.S. Air Force Can lead by Example on ULA, By JIM McALEESE posted: 28 November 2005 at http://www.space.com/spacenews/archive05/McAleese_112805.html

[15] One of the most definitive write-ups on EELV costs, with most numbers already distilled, is that of Jim McAleese at http://www.space.com/spacenews/archive05/McAleese_112805.html

[16] DTIC at http://www.dtic.mil/

Maneuvering through the site (DoD Websites > Federated Search) can take one to the [17]R&D Descriptive Summaries database (**Figure 3**).

Figure 2

Figure 3

By using keywords such as "evolved" a user can call up material such as shown in **Figure 4**.

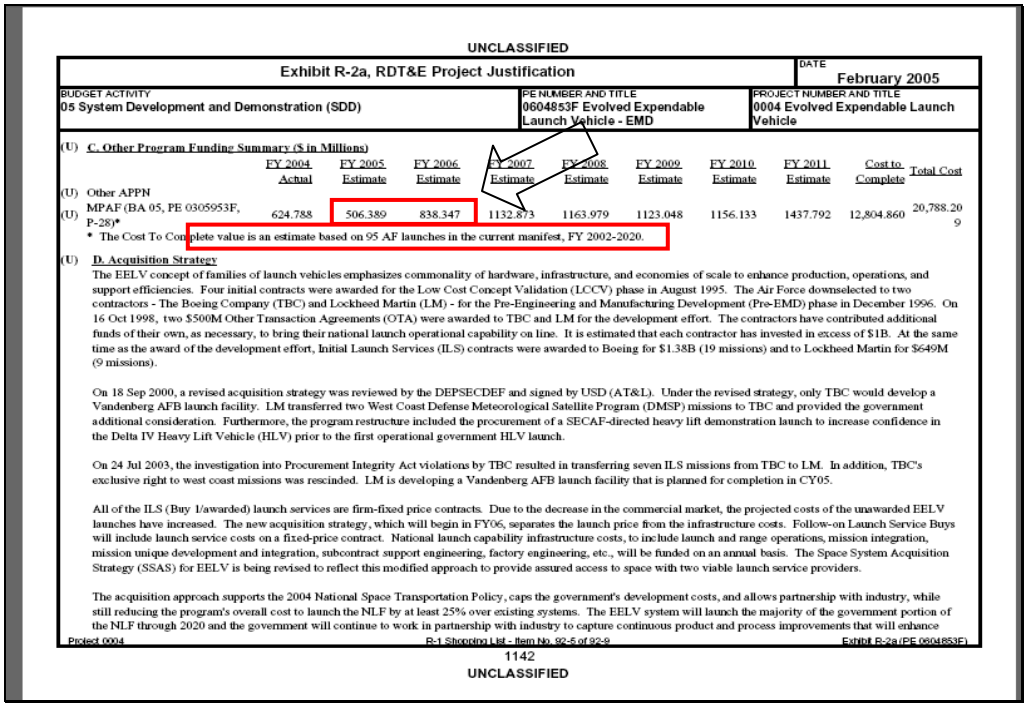

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Exhibit R-2a, RDT&E Project Justification		DATE: February 2005
BUDGET ACTIVITY: 05 System Development and Demonstration (SDD)	PE NUMBER AND TITLE: 0604853F Evolved Expendable Launch Vehicle - EMD	PROJECT NUMBER AND TITLE: 0004 Evolved Expendable Launch Vehicle

(U) C. Other Program Funding Summary ($ in Millions)

	FY 2004 Actual	FY 2005 Estimate	FY 2006 Estimate	FY 2007 Estimate	FY 2008 Estimate	FY 2009 Estimate	FY 2010 Estimate	FY 2011 Estimate	Cost to Complete	Total Cost
(U) Other APPN										
(U) MPAF (BA 05, PE 0305953F, P-28)*	624.788	506.389	838.347	1132.873	1163.979	1123.048	1156.133	1437.792	12,804.860	20,788.209

* The Cost To Complete value is an estimate based on 95 AF launches in the current manifest, FY 2002-2020.

(U) D. Acquisition Strategy

The EELV concept of families of launch vehicles emphasizes commonality of hardware, infrastructure, and economies of scale to enhance production, operations, and support efficiencies. Four initial contracts were awarded for the Low Cost Concept Validation (LCCV) phase in August 1995. The Air Force downselected to two contractors - The Boeing Company (TBC) and Lockheed Martin (LM) - for the Pre-Engineering and Manufacturing Development (Pre-EMD) phase in December 1996. On 16 Oct 1998, two $500M Other Transaction Agreements (OTA) were awarded to TBC and LM for the development effort. The contractors have contributed additional funds of their own, as necessary, to bring their national launch operational capability on line. It is estimated that each contractor has invested in excess of $1B. At the same time as the award of the development effort, Initial Launch Services (ILS) contracts were awarded to Boeing for $1.38B (19 missions) and to Lockheed Martin for $649M (9 missions).

On 18 Sep 2000, a revised acquisition strategy was reviewed by the DEPSECDEF and signed by USD (AT&L). Under the revised strategy, only TBC would develop a Vandenberg AFB launch facility. LM transferred two West Coast Defense Meteorological Satellite Program (DMSP) missions to TBC and provided the government additional consideration. Furthermore, the program restructure included the procurement of a SECAF-directed heavy lift demonstration launch to increase confidence in the Delta IV Heavy Lift Vehicle (HLV) prior to the first operational government HLV launch.

On 24 Jul 2003, the investigation into Procurement Integrity Act violations by TBC resulted in transferring seven ILS missions from TBC to LM. In addition, TBC's exclusive right to west coast missions was rescinded. LM is developing a Vandenberg AFB launch facility that is planned for completion in CY05.

All of the ILS (Buy I/awarded) launch services are firm-fixed price contracts. Due to the decrease in the commercial market, the projected costs of the unawarded EELV launches have increased. The new acquisition strategy, which will begin in FY06, separates the launch price from the infrastructure costs. Follow-on Launch Service Buys will include launch service costs on a fixed-price contract. National launch capability infrastructure costs, to include launch and range operations, mission integration, mission unique development and integration, subcontract support engineering, factory engineering, etc., will be funded on an annual basis. The Space System Acquisition Strategy (SSAS) for EELV is being revised to reflect this modified approach to provide assured access to space with two viable launch service providers.

The acquisition approach supports the 2004 National Space Transportation Policy, caps the government's development costs, and allows partnership with industry, while still reducing the program's overall cost to launch the NLF by at least 25% over existing systems. The EELV system will launch the majority of the government portion of the NLF through 2020 and the government will continue to work in partnership with industry to capture continuous product and process improvements that will enhance

Project 0004 R-1 Shopping List - Item No. 92-5 of 92-9 Exhibit R-2a (PE 0604853F)

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Figure 4

Note the increase of $331.06M going from 2005 to 2006, which would seem to confirm via a direct Air Force public source document the "infrastructure" cost correction previously referred to as in the "*$350 to $400 million"* range (in 2002). More importantly, knowledge of the planned / procured Air Force launches, removing any commercial launches, would lead to a simple perspective on per launch costs as follows in **Table 1**.

[17] R&D Descriptive Summaries database at http://www.dtic.mil/descriptivesum/

	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011
Missile procurement, AF (BA 05, PE 0305953F0)	Actual	BUDGET ESTIMATE	BUDGET ESTIMATE	BUDGET ESTIMATE	BUDGET ESTIMATE	BUDGET ESTIMATE	BUDGET ESTIMATE	BUDGET ESTIMATE
	624.788	506.389	**838.347**	1132.347	1163.979	1123.048	1156.133	1437.792
Number of Flights	5	6	6	6	6	6	6	8
		difference>	$ 331.96					
Portion that's ops driven (judgement)>			**0.5**					
ea.	$ 124.96	$ 84.40	$ 139.72	$ 188.72	$ 194.00	$ 187.17	$ 192.69	$ 179.72

Table 1

The number of DoD procured or planned launches can be gleamed from complementary sources such as the Teal "World Space Systems Briefing", "Atlas 5" section, but also by gleaming the phrase in the above **Figure 4** *"…an estimate based on 95 AF launches in the current manifest, FY 2002-2020."* The number 6 used in Table 1 would derive from the Teal report and is slightly higher than one would get by 95 launches over 18 years or 5.3.

In 2008 then it can be said, at least based on the prior, that if procuring about 5 or 6 launches per year for the government, with a long term plan of about 100 launches, then EELV launches will be a low of 1164/6 or **$194M** per launch to a high of 1164/5.3 or **$220M** per launch. This would be a match to the definition of "price" to the Government.

For a commercial customer the infrastructure subsidy can be expected to lower the price, as it is picked up by the Air Force. For NASA this too applies, as the launch provider does not attempt to recover this cost for the Air Force via any other customers, even if government. But, since the paradigm of "cost" in any case includes the cost to manage the acquisition it is worthwhile doing an exercise as to what NASA EELV launch costs would be for a few launches per year.

6. NASA – Other EELV Costs

NASA procures launch services from Air Force Expendable Launch Vehicles via the NASA Launch Services Program (LSP). There are two data points with which a bogey can be obtained here immediately. First to consider is the size of the KSC Launch Services Program Civil Service. Second would be the overhead attributable to these for KSC. Overhead in the case of KSC would be 1st order of the type referred to as "Center Management & Operations" (with inclusion of the facilities line item, and no further distinctions, as details into the nature of this overhead or definition are not the subject of this review). The LSP program consists of about 165 Civil Servants (obtained by counting the names on the KSC LSP organizational chart, dated 4/02/02). Overheads, taken to be proportional to that Shuttle is most of the KSC operation, whereas the International Space Station and Launch Services Program are both in the 10% range, would be about 3:1 (for obscure reasons, again, not delved into here). It can be shown, at various rates, that the total cost of this fixed management, engineering and technical oversight, with overhead support (procurement, finance, human resources, information technology, security, etc) would be in the range of $50 to $70M a year regardless of launch rate. Therefore, final "EELV costs to NASA" on average, would be another $15M to $20M per launch. The total EELV launch costs to NASA would then be in the range of **$210 to $230M** per launch (assuming a steady few launches procured by NASA every year).

7. Conclusions

1. The United States EELV type dual-provider / dual infrastructure, providing anywhere from a few to upwards of 6 launches per year for the DoD, but generally regardless of total flight rate, is an upwards of $1.2Billion dollar recurring yearly cost comprised of actual launch effort and, significantly, of simply maintaining the productive infrastructure.

2. Acquisitions of such services can expect "prices" or "procurements" as external facing costs of at least $200M per launch if such acquisition framing "per launch" can be achieved and is a paradigm or metric of some use.
3. It is obvious that the matter of costs and launch vehicles continues to be an area where new ventures fail to communicate, by hiding, misunderstanding, neglecting to study, or simply misleading, the true scope of resources required to keep and operate a launch system. When congressionally mandated Nunn-McCurdy correction reporting reaches a scope of a program having to report jumps from [18]$18.8 billion to a $31.8 billion, the situation is not only dire, it must by definition have poor estimation colluding with lack of interest.
4. While high-level data sources and the varied mix of sources can reconcile to agree on some key EELV cost parameters, it is not clear without further detail that a true picture of EELV costs will emerge in the near future. The approval of the [19]United Launch Alliance, merging Atlas and Delta, Boeing and Lockheed-Martin launch operations, can reasonably be expected, by way of full monopoly, to only make this lack of transparency worse. Future initiatives on the part of the Government should include the possible breakup of launch vehicle services from any spacecraft providers similar to the [20]anti-trust guidelines that keep airliner manufacturers such as Boeing from owning airline operations such as American. Co-ownership is NOT healthy, long term. Immediately the cost of the launch would be visible, albeit at a high-level, as apart from the spacecraft on any bids, making it possible to compare a Northrop-Grumman or a Space-craft-R-Us proposal by a manufacturer only in the satellite / spacecraft business against any other (vs. trying to figure out the equalizing difference when a launch vehicle provider also bids for a constellation of spacecraft, to be launched on their own launch vehicles). The latter break-up notion could possibly interplay with any eventual merger between ULA and United Space Alliance (USA) at KSC (albeit opening new problems as to sheer size). In either case, initiatives exploring new legal or procurement methods should focus on having a healthy understanding of costs, which is critical to future US pre-eminence in space. You can not control what is not understood.
5. Further analysis here would combine DoD "costs" and the actual commercial launches that are occurring into one cohesive picture. The later likely already contribute to keeping the costs discussed here from escalating even further. Again, a truthful analysis would distinguish fixed costs regardless of who is paying, rigorously studying and defining this category to include only those costs that are minimally required to provide at least 1 (and possibly zero) but no more than X number of launches per year. Variable costs would similarly be attacked. Lastly non-recurring capital expenses that occur when a launch rate jumps from X to Y would be separated. As with Shuttle, EELV visibility would be down to [21]at least 8 categories as follows - (1) contractor hands-on costs by task, i.e. technicians, on vehicle as well as for dedicated

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[18] Jim McAleese at http://www.space.com/spacenews/archive05/McAleese_112805.html, "This dominance by EELV of the Air Force Missile Procurement Account arose when the EELV program experienced cost growth in December 2001, September 2002, and September 2003, before dramatically breaching the Nunn-McCurdy Act with an unexpected $13.3 billion projected cost growth in December 2003, when the total projected EELV program costs for the period 2004-2020 exploded upward from an estimated $18.8 billion to a projected $31.8 billion. This was primarily due to the lack of a commercial launch vehicle market to absorb recurring overhead and allocable infrastructure costs."

[19] "United Launch Alliance nears approval" at http://www.spacetoday.net/Summary/3309

[20] White Paper: "Independent Space Transportation Operator Concept, A Breakthrough Acquisition Strategy Using Independent Space Transportation Operators, Making Affordable and Sustainable Space Transportation Possible", C. McCleskey, Systems Engineering Office, Spaceport Engineering & Technology Directorate, NASA John F. Kennedy Space Center, Florida, May 18, 2004. at http://science.ksc.nasa.gov/shuttle/nexgen/space_trans_afford_main.htm

[21] Is there anything else you would like with that Sir? Probably, such as associations to specific flows or specific budget years. Org. charts too.

infrastructure, as labor-hours (2) contractor engineering, safety & quality, (3) contractor in-direct & program management (literally dozens of functions from work control to scheduling), (4) contractor logistics, (5) sub-contractors to the main contractor, (6) government direct employees (engineering & technical as well as direct management), (7) government in-direct (such as procurement, human resources, security, finance, etc), and lastly (8) infrastructure of the base or center type (i.e. basic roads, utilities and communications, etc). Some of these, such as government in-direct or base infrastructure, would be allocations off some total expense picture dependent on the size of the other EELV resources (categories 1-6) drawing on the later resources.

6. Further debate is likely, and healthy, especially as regards infrastructure costs, who pays for what, and high-level comparisons against human space flight so as to define why no launch business, even after investing Billions in new systems, has failed to develop either new launch providers, or significantly greater access, [22]tonnage, reliability or routine access to space and beyond.

8. About the Author

Mr. Zapata has worked with NASA at the Kennedy Space Center for over 18 years. In that time he has held responsibility for Shuttle systems including the Shuttle External Tank and the Shuttle cryogenic propellant loading systems, and related systems. For over a decade he has worked to translate the operations experience into improvements in flight and ground systems design so as to achieve improvements in ground processing operations from landing through launch, in all aspects from direct to in-direct operations areas. Most recently he participated in the Explorations Systems Architecture Study or "ESAS" contributing Launch and Landing Ground Operations cost estimation and integration into life-cycle cost analysis processes to decide the new NASA architecture to follow the Space Shuttle. Mr. Zapata looks forward to a day when access to space is safe, routine and affordable as a result of taking advantage of, quantifying, and understanding the experience and lessons of ongoing space transportation systems operations.

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[22] By way of example on tonnage per flight (*though per year is the more useful metric*), Delta VI tonnage to ISS, 407km X 407km, 51.6 degress, is **22,560** kg using the Heavy configuration. Tonnage for Delta from the National Security Space Launch Report, page 18, at http://www.rand.org/pubs/monographs/MG503/ The NASA Exploration program Crew Exploration Vehicle / Ares I requirement is given by the Constellation Architecture Requirements Document by "Orion shall have a Control Mass of **25,324** kg (55,830 lbm) at Lift-Off for the ISS Mission." Also "Orion shall have a Control Mass of **28,059** kg (61860 lbm) at Lift-Off for the Lunar Mission."